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An approach to acorn production in Iberian dehesas

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Abstract Acorn production is one of the most important products in silvopastoral systems in the Mediterranean region. In the present study we carried out two preliminary trials to analyze the distribution of production over time and the effect of pruning. The objective was to develop tools to manage this valuable resource within these systems. In the first part of the study, we analyzed the total acorn production of a holm oak stand, and its seasonal distribution (October–January) over two years (1997–1998 and 1998–1999) in five sites in the southwest of Spain. Mean total acorn production ranged from 590 to 830 kg ha^{-1}. There was considerable variation between the different sites and years studied, as was expected from studies on other oak species. A comparison was also made of acorn production, comparing annual acorn production between 40 pruned and 40 non-pruned trees, for the period 1994–1999. There was an interaction between 'pruning treatment' and 'year'. Pruning, significantly decreased acorn production in all but two years when production was above the average, whereas production was not affected by pruning the three years that acorn yield was below the average. The study of acorn production and the analysis of the effect of pruning, needs to be studied over a longer time period.

Keywords Extensive pig farming · Fruit yield · Woodlands · Pruning · *Quercus ilex* · *Quercus suber* · Curculio

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Introduction

The genus *Quercus* (oaks) is one of the most widespread in the Northern Hemisphere, oaks being the main components of the tree stratum in many forests and woodlands. As a consequence of its importance, much information has been produced about the acorn production of many oaks especially in North America (Aizen and Woodcock 1992; Sork et al. 1993; Koenig et al. 1994; Abrahamson and Layne 2003), but also in East Asia (Masaka and Sato 2002; Maeto and Ozaki 2003). In Europe, and specifically in the Mediterranean region, despite the great importance of oaks, there have been few studies of acorn production, even though acorns play a basic role in domestic and wildlife feeding.

The *dehesa* ecosystem consists of oak woodland with an understory composed of a mosaic of croplands, grasslands and shrublands, where cattle, sheep, pigs and goats are extensively raised (San Miguel 1994; Joffre et al. 1988; Martín-Vicente and Fernández-Alés 2006). The mean tree density is around 30–50 trees ha^{-1}, varying from isolated trees to complete tree cover (over 100 trees ha^{-1}). Pruning to obtain firewood is a traditional activity which has been retained even though firewood has lost almost all its value. Coppice originated from firewood exploitation is common on the steepest slopes and shallowest soils, and plays an essential role in creating wildlife habitat and game species. Game, both small and large, are gaining importance as an income source, due to the changes in socio-economic structure which have occurred over the last four decades (Pinto-Correia 1993; San Miguel 1994).

The effect of pruning in Mediterranean oak woodland has long been controversial. There is insufficient information based on research even to form an objective and rational opinion upon the response of trees to this important silvicultural practice. Light or moderate pruning is likely to be good for the tree. Pruning of overshadowed and weak branches (with a negative energy balance (more carbohydrates are lost by respiration than gained by photosynthesis)) is thought to be beneficial (Hubert and Courrand 2002). The economic costs of light or moderate pruning are very high, and there are attempts to compensate these costs by obtaining income from firewood, charcoal or virgin cork. This generally implies an increase in the intensity of pruning, which can be too intense and cause damage to the tree.

There is also a traditional belief that pruning increases acorn production (San Miguel 1994; Gómez and Pérez 1996). Acorn production is nowadays one of the most profitable products in the *dehesa* system, as Iberian pigs, the most efficient acorn consumer, are raised extensively by feeding on acorns during the fruiting period. An individual, fed only on acorns and grass, can consume 7–10 kg of acorns per day in the *dehesa*. This coincides with the end of their fattening period, when they increase weight from 100 to 160 kg (López-Bote 1998; Nieto et al. 2002). Holm oak (*Quercus ilex* Lam ssp. *ballota*) and cork oak (*Quercus suber* L.) are generally the dominant tree species, and their acorns are consumed in preference to acorns from other oak species present.

The understanding of fruit production is basic to this ecosystem in order to achieve a sustainable management and enhance pig and wildlife feeding. Though some studies have been conducted on several aspects of acorn production in this ecosystem, this phenomenon is still poorly understood. Most of the literature produced is sparse and dispersed among small local studies.

The objective of this work is two-fold: (1) estimate the annual acorn production and the seasonal distribution on acorn fall; (2) analyze the effect of pruning on acorn yield.

Materials and methods

Two different trials have been performed to increase the knowledge in acorn production on two of the most important Mediterranean *Quercus* species, and acorn production relationship with the management techniques traditionally applied in the *dehesa* system.

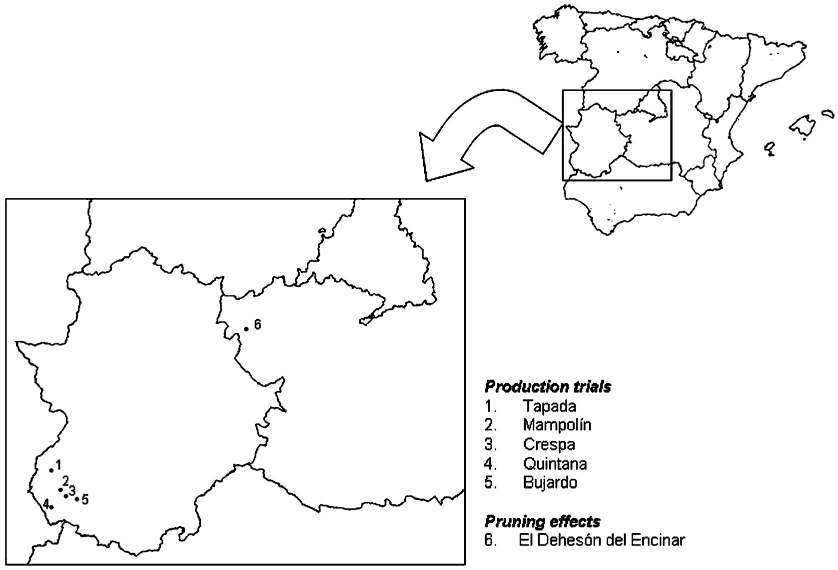
Production trials

The study was carried out on five sites representative of the Spanish *dehesa* system (Fig. 1) in the southwest of the province of Badajoz (Extremadura, Autonomous region). The soil texture is loam, with pH range of 6–6.9 and low organic matter content (range 0.7–1.9%). The climate is semi-arid Mediterranean. Tree density varies from 20 to 45 trees ha^{-1} and acorn crops were studied during the years 1997–1998 and 1998–1999.

Acorn production and its distribution along autumn–winter, were sampled using the method proposed by Zulueta and Cañellas (1989). One container was placed under each tree (0.283 m^2 $tree^{-1}$), estimating acorn production from four trees per site.

Insect infestation, production and distribution of acorn fall were estimated every 15 days from 1 October 1997 to 15 January 1999. Acorn samples

Fig. 1 Location of the experimental sites



were dried at 80°C for 48 h and weighed to the nearest 0.01 g. We used ANOVA to test differences among years and sites.

Pruning effects

A pruning trial was carried out in the 'El Dehesón del Encinar' estate (Castilla-La Mancha, autonomous region, see Fig. 1). The current vegetation consists of a mixed holm oak-cork oak *dehesa*. The climate is continental Mediterranean, varying from year to year between arid to sub-humid. Mean annual rainfall in the study site is 573 mm and mean annual temperature 15.2°C with the period from October to April liable to frost. Soil is sandy (> 80% sand) of granite origin, with pH of 5.5 and organic matter below 1%.

Acorns were collected from 40 cork oak trees pruned in December 1993, and 40 left un-pruned. Cork stripping took place in August 1998, at the end of a ten-year cycle. Trees were selected in pairs according to their circumference over cork at breast height, covering all the diameter classes present in the area. A moderate pruning treatment was applied, removing around 30% of crown biomass. Circumferences before stripping (CSC), at the trunk base (CB), at the trunk midpoint (CM), and on the upper limit of the trunk (CS) and height reached when stripping (HD) were recorded for each tree. Stripping coefficient was calculed as the relation between stripping height and circumference over cork at 1.3 m. Acorns were collected in one 0.3025 m^2 trap $tree^{-1}$ placed randomly below each tree crown. Falling acorns were collected monthly from September 1994 to March 1999. Acorns were dried at 80°C for 48 hours and weighed to the nearest 0.01 g.

Silvicultural characteristics of pruned and unpruned trees were compared using paired *t*-tests. The effect of 'year' and 'treatment' on total acorn production (period considered: august–february) was analyzed using a two-factor ANOVA. 'Year' is considered a fixed effect in this study as we were interested in checking whether there was an interaction between the pruning effect and year, in order to test whether the pruning treatment was only significantly affecting the year acorn production when was above the average (i.e. considered a 'good' year for acorn production). Comparisons between means were done using the Tukey test. Acorn production was log-transformed (log + 1) to approach normality. All tests were performed with $\alpha = 0.05$.

Results

Production trials

Annual acorn production for the different study sites is shown in Fig. 2. The mean total annual acorn production ranged from 590 to 830 kg ha^{-1}.

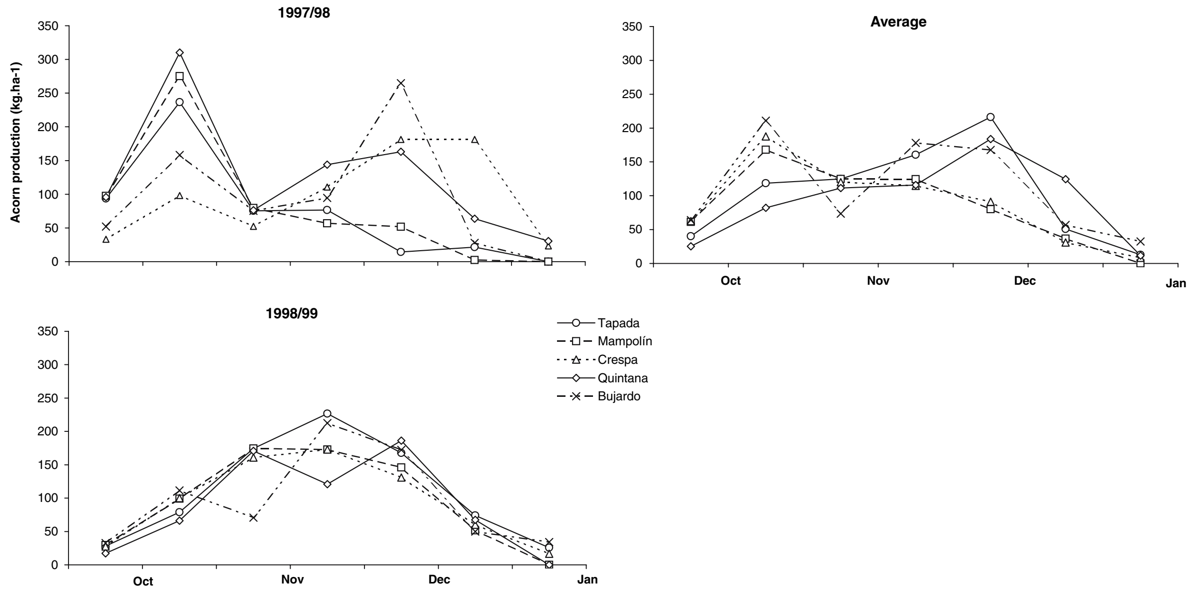


Fig. 2 Acorn fall distribution for the years 1997/1998, 1998/1999, and its average.

Acorn yield varied between the different study sites and years (Fig. 2) depending on the sites: in one site we found an increase of 26.5% over the average, while in other site there was a decrease of 25.3%. During the second year distribution could be considered ideal (a progressive acorn fall) forming a Gaussian curve and near-uniformity throughout the year, while in the first year production was more spread in intensity across the five study sites.

Attacks to acorns, by the insect *Curculio elephas* Gyll., were greater during the first year (24–49% of the fallen acorn in October) than in the second year (7–17%).

Pruning effects

Pruning had no significant effect on silvicultural characteristics such as tree size and intensity of cork stripping, (Table 1).

The estimated acorn production (expressed in units per crown projection area) was analyzed through five annual cycles (1994–1999) as a function of the pruning treatment (Table 2). Acorn yield varied greatly between years (Table 2). A large fall of acorns in 1994 was followed by a low fall over the next three years (Fig. 3).

The interaction between 'Treatment' and 'Year' was significant ($F_{4,390} = 4.81$, $P < 0.001$), hence the pruning effects were analysed for each year separately (Table 2). There were significant differences in the years 1994 and 1998 (see Table 2) between the pruned and un-pruned trees, coinciding with the two years where acorn production was above the average. Whereas, when acorn production was below the average

Table 1 Average tree characteristics of the cork oak pruning trial plots. Standard deviations are between brackets

Variables	Treatment	
	Pruned	No pruned
Circumference over cork (cm)	134 (30)	141 (29)
Circumference at the top of trunk over cork (cm)	126 (34)	135 (37)
Circumference in mid-point of trunk over cork (cm)	122 (34)	127 (34)
Circumference at the base of trunk over cork (cm)	147 (41)	157 (37)
Height stripped in trunk (cm)	247 (68)	264 (95)
Stripping coefficient[a]	2.10 (0.50)	2.22 (0.51)

[a] Relation between stripping height and circumference over cork at 1.3 m

Table 2 The effect of pruning on acorn production (ANOVA)

Year	Mean (g m^{-2})		
	No pruned	Pruned	Average
1994–1995	332.85 ± 340.02 a	137.03 ± 322.13 b	237.39 ± 343.73
1995–1996	0.55 ± 1.65 c	1.43 ± 8.21 c	0.98 ± 5.83
1996–1997	57.96 ± 115.02 d	55.76 ± 108.39 d	56.89 ± 111.13
1997–1998	29.97 ± 61.00 e	32.05 ± 67.38 e	30.98 ± 63.78
1998–1999	305.08 ± 312.21 f	139.64 ± 167.91 g	224.43 ± 264.27
Average	145.28 ± 256.37	73.18 ± 179.43	–

Different letters indicate statistical differences at $\alpha = 0.05$ between years (standard deviations). As the interaction between 'Pruning treatment' and 'Year' was significant, comparisons were calculated independently for each combination of factors

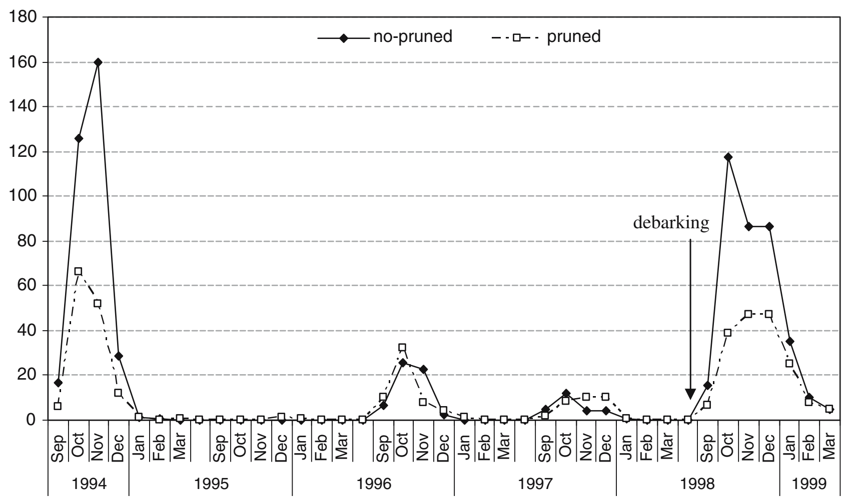


Fig. 3 Seasonal distribution of acorn fall in pruned and un-pruned cork oak trees (expressed in g m^{-2} of crown surface). Data from September 1994 to March 1999

(the other three years studied), production was unaffected by pruning.

Discussion

Production trials

The differences in the distribution of fallen acorns during the first year of the trial was probably related to a very wet autumn which triggered *Curculio elephas* and *Cydia* sp. infestation (Soria et al. 2005), provoking sudden acorn fall in October (38% of total production) and reduced fall in November (approx. 23% of total). In contrast in the second year the expected maximum in acorn fall occurred in November.

Many factors determining fruit production in woody species are still unknown. The great variability reported by all authors in *dehesas* (Martín et al. 1998; Álvarez et al. 2004; Carbonero et al. 2003) both between individuals and within individuals between years is common to most other woody species, although the precise reasons explaining this phenomenon are not known (Sork et al. 1993; Herrera et al. 1998; Koenig and Knops 2000).

Production per crown unit area is the most objective way to measure acorn production and compare between different stands and locations. Holm oak acorn mean values in the literature are around 100 g m^{-2} of crown cover and 15–21 kg tree^{-1} (Gea-Izquierdo et al. 2006). Our results are similar to other results from dehesas within 8 provinces of Spain, in 10 years from Torrent

(1963), who found a mean annual average (± standard deviation) of 586.4 (± 131.6) kg ha^{-1}. Similar average values around 500 kg ha^{-1} are also reported (e.g. San Miguel 1994). In contrast, Martín et al. (1998) report mean values around 300 kg ha^{-1}, which is much lower than those found in this study and could be related to different stand characteristics such as density. Within the same location, it is possible to find individuals without acorns while other trees can produce in the best years more than 155 kg tree^{-1} (Carbonero et al. 2003). Other authors have recorded up to 300 kg tree^{-1} (López-Carrasco, unpublished data).

The negative effect of insects can be very intense in some years, with reductions in acorn yield of up to 50% (Espárrago et al. 1993; Soria et al. 1996). It has been found that other oak species of some insect life-cycles can adjust to two or more year patterns. This suggests a possible adaptation to mast fruiting as insects would synchronize their diapause to fruit production (Maeto and Ozaki 2003). The existence of an interaction between precipitation and insect infestation (heavy rain in October and *C. elephas* attack) is believed to be frequent in the south–west of Extremadura, at least from general observations from rain measurement reports and plague controls.

The incidence of insects, and to a lesser extent, frost, has a considerable effect on acorn yields and morphology. It is common that the effect of insect infestation, particularly *Curculio elephas* and *Cydia* sp. (the species affecting acorns in this study), provokes the early falling of acorns and later on reduces significantly the acorn weight (both dry and fresh) and size. Soria et al. (1996) report a reduction of approx 4% in the mean acorn width (1.58 cm) in infested acorns, whereas acorn length remains the same (mean 3.4 cm). In the literature, sound acorns are reported to be heavier than acorns injured by insects 3.73 g and 2.99 g, respectively as found Soria et al. (1996). No significant differences have been observed in the effect of the different insect species (Soria et al. 1996). Pigs consume selectively the biggest sizes, which probably coincide with the sound acorns (García et al. 2003).

Pruning effects

From the study it is not clear whether pruning enhances acorn production, as is traditionally believed (San Miguel 1994). It is difficult to obtain any conclusions from the existing studies, as most of them lack many necessary details, such as production previous to pruning and stand characterization (especially tree diameter distribution and crown sizes), and do not study a whole pruning period (between 10 and 20 years). (Gómez and Pérez 1996; Álvarez et al. 2004). The present study also suffers from some of these shortcomings: there are no records from before to pruning and our study period is still too short to evaluate a whole pruning cycle (between 10 and 20 years; Gómez and Pérez 1996). However, as an approach, this study is valuable as a basis for the necessary longer studies to demonstrate if there is a response in acorn production to pruning.

Most authors report a decrease in production during the first year after pruning (Porras 1998; Carbonero et al. 2003; Álvarez et al. 2004). This might be explained as the tree reallocating of resources to rebuild the aboveground biomass. Acorn production results over two years after pruning are not conclusive, although some authors report a decrease up to the second year with an increase thereafter (Porras 1998). In our results, pruning clearly reduced production the years above the average (‘‘masting years’’), which could be partly a result of lower crown volume after pruning. Therefore, our results would question the assumption that pruning enhances acorn production.

This conclusion may be dependent on the type of pruning carried out. Nevertheless, there is no agreement between authors on whether the type of pruning is influential or not (Álvarez et al. 2004). Most pruning and production studies have been conducted on holm oaks. Flowering and fruiting phenology is more complex in cork oak than in holm oak (flowering and fruiting cycles of 1, 1.5 or 2 years), and this could influence any comparisons between the species.

As the existence of a positive effect of pruning on acorn production is not clear, and currently charcoal and firewood are depreciated in value, although pruning might be unprofitable from an economic point of view it provides work for people in deprived areas and may have other socio-economic benefits.

More studies on acorn production in *dehesa* system are needed to fill the lack of knowledge on this topic. It is necessary to study in depth the effect of the main silvicultural treatments (fertilization, ploughing, pruning, density regulation,..), specially in a very harsh and changing ecosystem like the Mediterranean open landscapes.

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